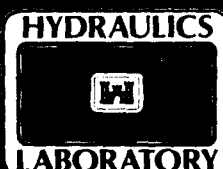
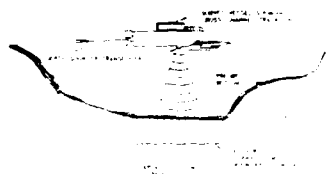
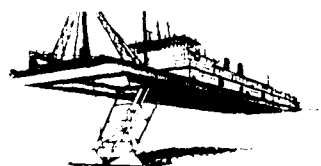




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IMPROVEMENT OF OPERATIONS AND MAINTENANCE
TECHNIQUES RESEARCH PROGRAM

TECHNICAL REPORT HL-90-17

SAND WAVES

Report 2

ENGINEERING CONSIDERATIONS AND
DREDGING TECHNIQUES

by

Michael P. Alexander

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY

Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



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<p>This report provides guidelines for identifying, surveying, and accurately calculating dredging volumes for sand waves in navigation channels. Longitudinal and cross-channel surveying practices are evaluated and discussed as they pertain to sand waves. Volume calculation methodology is then presented in relation to sand wave dredging volume estimation.</p> <p>Conventional dredging methods and procedures are discussed as they pertain to sand wave dredging. Although conventional dredge types are effective at sand wave mitigation, inefficiency is a problem. The unique shape of sand waves in navigation channels has led to experimentation and development of innovative leveling techniques. These experiments and techniques are also described.</p> <p style="text-align: right;">(Continued)</p>					
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Recognizing and understanding the sand wave problem in navigation channels establishes the need for a cost-effective specialized dredge or dredging technique. This report provides a basis for coupling continued sand waves research with dredging equipment designs while providing guidance to maximize the efficiency of current dredging practice. (5D) 1

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PREFACE

The sand waves research effort resulting in this report was sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), under the Improvement of Operations and Maintenance Techniques (IOMT) research program, Work Unit No. 32386, "Mitigating Sand Waves in Navigation Channels." This report is the second in a series designed to evaluate sand wave problems in navigation channels and develop mitigation alternatives. Report 1, "The State of Knowledge of Sand Waves in Navigation Channels," outlines relevant theoretical descriptions, laboratory studies, and field studies. The research was carried out at the Coastal Engineering Research Center (CERC) with assistance from the Hydraulics Laboratory (HL) at the US Army Engineer Waterways Experiment Station (WES).

The report was written by Mr. Michael P. Alexander, Engineering Applications Unit, Coastal Structures and Evaluation Branch, Engineering Development Division, CERC (currently in the Estuarine Engineering Branch, Estuaries Division, HL), under the supervision of Dr. James R. Houston, Chief, CERC; Mr. Charles C. Calhoun, Assistant Chief, CERC; Mr. Thomas W. Richardson, Chief, Engineering Development Division; Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch; Dr. Yen-hsi Chu, Chief, Engineering Applications Unit; and Mr. Robert F. Athow, Estuarine Engineering Branch, IOMT Program Manager. Mr. Jim Gottesman is HQUSACE Technical Monitor. Technical review of this report was provided by Messrs. W. J. Lillycrop, T. N. McLellan, and Dr. Yen-hsi Chu, Engineering Applications Unit; Mr. Mitchell A. Granat, Estuarine Engineering Branch; and Dr. G. A. Zarillo of the Florida Institute of Technology, Melbourne, FL, under the Intergovernmental Personnel Act. Assistance with drafting and report preparation was provided by Ms. Dawn M. Logue. This report was edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
knots (international)	0.5144444	metres per second
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	square metres
tons (2,000 pounds mass)	907.1847	kilograms

SAND WAVES
ENGINEERING CONSIDERATIONS AND
DREDGING TECHNIQUES

PART I: INTRODUCTION

Background

1. This report is the second in a series designed to evaluate sand wave problems in navigation channels and develop mitigation alternatives. Report 1 (Lillycrop and Alexander, in preparation) outlines the state of knowledge of sand waves. This report focuses on engineering considerations, more specifically correctly recognizing, surveying, and computing dredging volume estimates for sand wave problem areas. Also evaluated and discussed in this report are conventional and innovative dredges and dredging techniques that have been or are currently used for sand wave mitigation. Other reports to follow will present analytic and empirical tools for channel designs that minimize sand wave formation along with dredging equipment and/or practices that more efficiently mitigate sand wave problems.

2. A sand wave can be defined as a wavelike bed form that will, under conducive flow conditions, develop to the point of interfering with navigation in a waterway. Although sand waves have no average dimensions, because of their dynamics and dependence on site-specific hydraulic conditions, sizes have been documented between 3 and 20 ft* in height with wavelengths (linear crest to crest dimensions) between five hundred and several thousand feet (Lillycrop and Alexander, in preparation). The heights of sand waves (Figure 1) become most pertinent to navigation. In low flow regimes in rivers, bed forms have been described as ripples and dunes. During higher stages, riverine flow regimes may produce dunes, chutes and pools, and sand waves. Following a dredging operation that results in a nearly flat channel bottom, ripples, megaripples, and then sand waves are the common terms that have been used to describe the evolution of bed forms in a coastal environment (Lillycrop, Rosati, and McGehee 1989). Since the terms dune and megaripple are

* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 4.

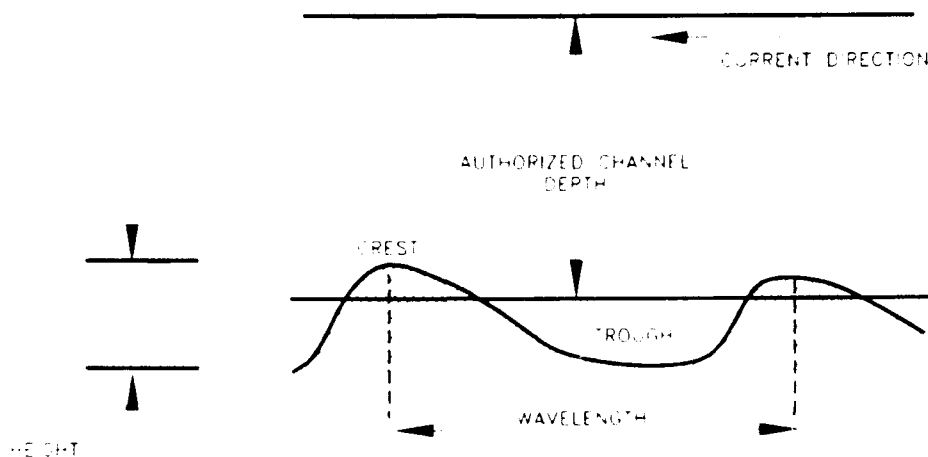


Figure 1. Sand wave crest protrusion into channel dimensions

typically used synonymously, the latter terminology of flat bed, ripple, mega-ripple, and sand wave will be adhered to in this and subsequent reports. (A more complete explanation of such terminology and related geomorphic characteristics can be found in Lillycrop and Alexander (in preparation).) The term sand wave will be used throughout this report to describe the wavelike bed forms that interfere with navigation in waterways. This term is generally descriptive of a bed form large enough to interfere with navigation, as well as large enough to warrant specialized mitigation techniques beyond conventional dredging and disposal. Inquiries to US Army Corps of Engineer Districts have identified sand waves as a fairly prevalent form of navigation interference in all types of dredging environments (Figure 2). The point is that sand wave mitigation can be an effective dredging specialty for Corps projects.

3. Two general approaches can be taken to mitigate a sand wave navigation problem. As discussed in Lillycrop and Alexander (in preparation), the first alternative is through development of sand wave dredging procedures and equipment. The second alternative is to change the channel design or modify existing structures to alter local sand wave-conducive hydrodynamic conditions. For example, a narrower inlet may be constructed with a smaller cross-sectional area, thereby eliminating the flow regime that causes sand wave formation. Such an approach might entail extensive dredging and new jetty construction, an extremely expensive solution for most situations. This report deals with the former approach, improved dredging techniques.

4. A variety of designs and approaches may arise in discussions

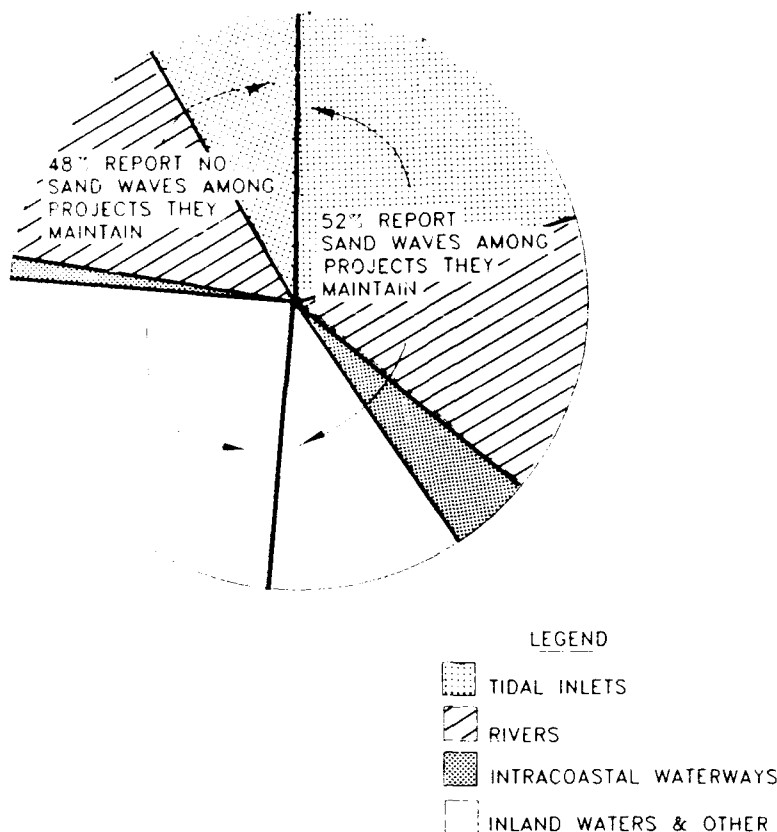


Figure 2. Percentage of Corps Districts and Area Offices reporting on the presence of sand waves among their dredging projects

concerning sand wave dredging problems and solutions. Searching for "new" ideas can often lead to discovering that the approach or device in question has been tried before. For instance, a recent design to use submersible slurry pumps on a short discharge line for sand wave dredging closely matches dustpan dredging concepts, but can easily be considered an innovative approach. Specialized sand wave dredging equipment designs are currently in infancy. Considerations for developing a specialized approach with the goal of increased dredging efficiency are (a) material volumes, grain size, and transfer distance; (b) re-formation dynamics; and (c) environmental statutes. Formation/re-formation dynamics remain unknown at most sand wave problem areas. Understanding the dynamics and causes of sand wave formation and migration will provide a basis for improving equipment designs and project planning aimed at extending conventional dredging intervals.

5. It should be noted that the dredging and leveling techniques and concepts described in this report may apply to other types of maintenance

dredging as well. A device or technique for sand wave mitigation might prove effective at an encroaching sand bar on a river. Another situation might incorporate sand wave mitigation techniques at an inlet entrance bar formed by wave action and longshore transport. Sand waves by definition are significant problems on their own, but these situations are mentioned so that the reader understands the value of cross-application of sand wave mitigation techniques.

Purpose

6. The purpose of this report is to raise awareness of a specific shoaling problem, sand waves; provide guidance on how to calculate accurate dredge volumes; and discuss dredging methods capable of mitigating this problem. Sand wave shoaling is not a new problem in waterway management. Early attempts at dredging were directed at leveling bed forms that created navigation hazards (Ockerson 1898). Such techniques led to the development of the pipeline dredge. Increasing fuel, maintenance, and other conventional dredging costs have shifted dredging research in more efficient, specialized directions. This report provides guidance on identifying the sand wave problem and discusses the current state of specialized as well as conventional maintenance techniques.

Scope

7. This report is divided into three major categories. Part II, "Engineering Considerations," includes information on correctly identifying a sand wave problem. Basic engineering considerations for sand wave problem mitigation include recognizing the shoaling as a sand wave, and then properly calculating a dredge volume pay yardage. Once the basic recognition and volume calculation guidelines are determined as they apply to sand wave shoaling, conventional mitigation techniques are presented and evaluated in Part III. Various innovative techniques are discussed in Part IV. These techniques are presented to lay the foundation for continued research and experimentation in an effort to develop successful dredging techniques for sand wave problem mitigation.

PART II: ENGINEERING CONSIDERATIONS

Recognizing the Problem

8. Engineering considerations for any dredging project include determining the limits of dredging, the volume of material to be removed, and special requirements such as environmental constraints. Most considerations are site-specific and will become obvious to the planner as work progresses. Identifying and calculating a dredging volume over a sand wave field requires specialized hydrographic survey practices.

9. Hydrographic surveying has undergone rapid advancement in recent years. Computerized and automated survey systems have led to more accurate and precise soundings as well as rapid field collection rates. With today's computer technology, data processing requires only a fraction of the time that graphical/manual calculations require. Although modern technology has improved precision, accuracy, and operating procedures while reducing data processing time, most surveying systems still operate with a single transducer.* This equipment characteristic requires appropriate track line planning in order to identify sand waves.

10. Sand waves are spatially asymmetric; therefore, their irregular shape may not "average out" in a conventional cross-channel template volume computation. Cross-channel surveys can lead to erroneous volume calculation by excluding sand wave contribution (or lack of contribution) in the calculations. Cross-channel surveys involve sounding perpendicular to the center line of a navigation channel. This allows a cross-sectional plot of the pre-dredging and postdredging channel bottom in relation to authorized or specified template depths and side slopes (Figure 3). Errors are introduced in dredge volume computations when the survey tracks cross only the crests or troughs of sand waves. Two extreme cases are shown in Figures 4 and 5. Because of the expense associated with dredging in general, the calculation of pay yardage is critical. This becomes very important for sand wave dredging, because improper surveying leads to inaccurate estimates of pay yardage, either under or over the actual volume that needs to be dredged. Applying

* Some Corps Districts currently operate multitransducer sweep systems capable of complete bottom (and therefore bed form) coverage. Such systems may one day be commonplace, making bed form detection much easier.

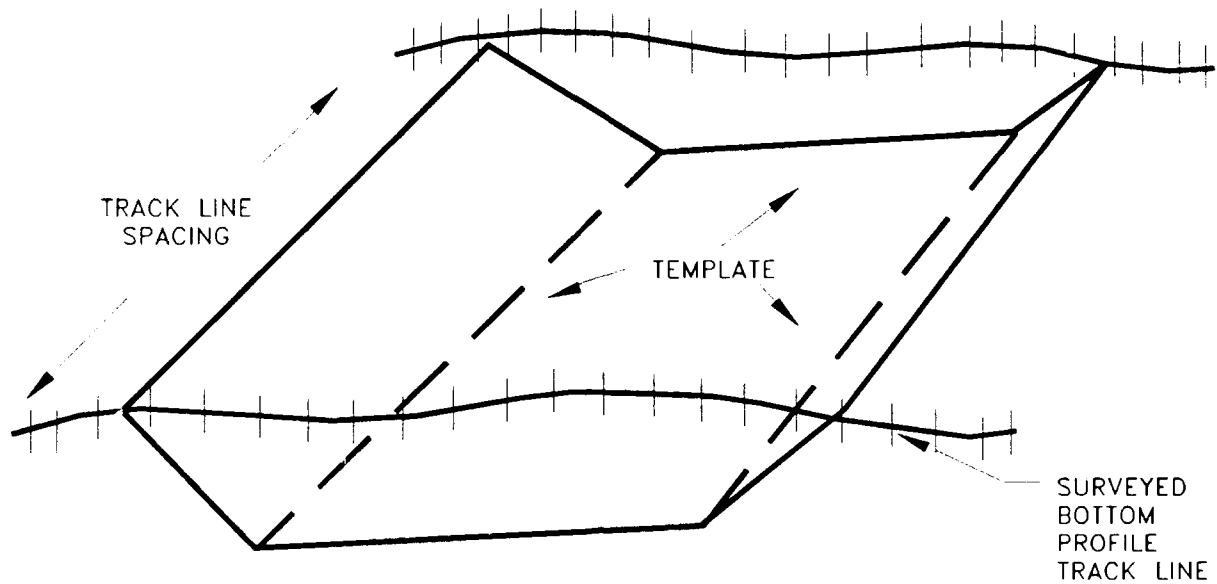


Figure 3. Typical channel template profile schematic

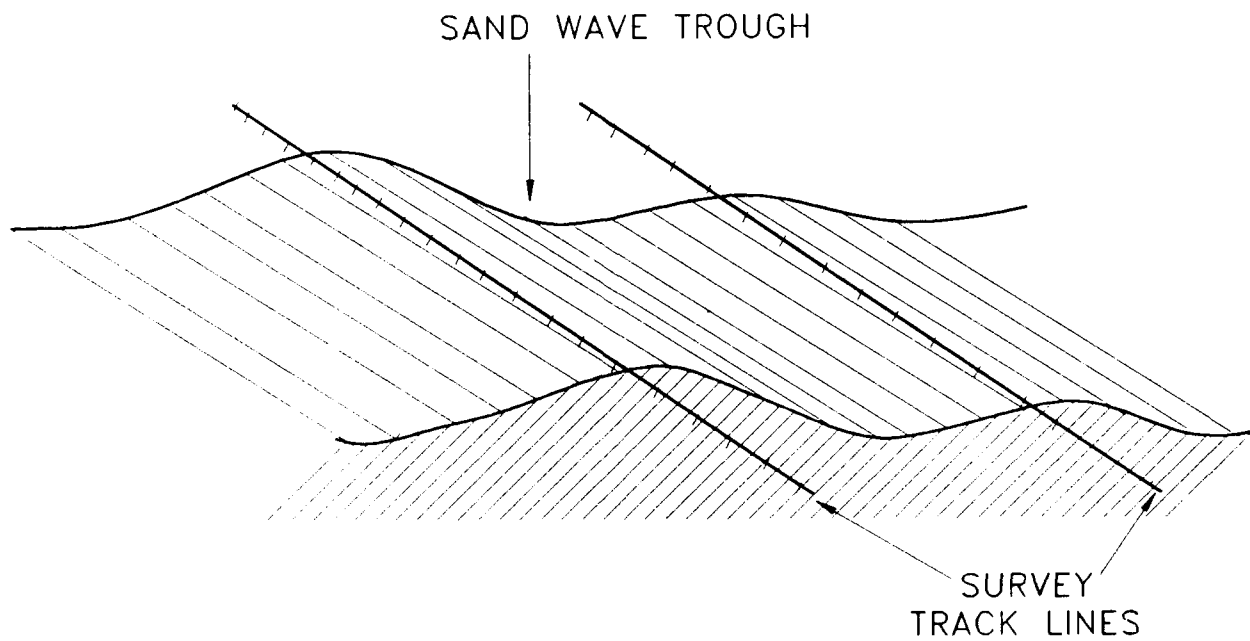


Figure 4. Survey track lines missing sand wave trough

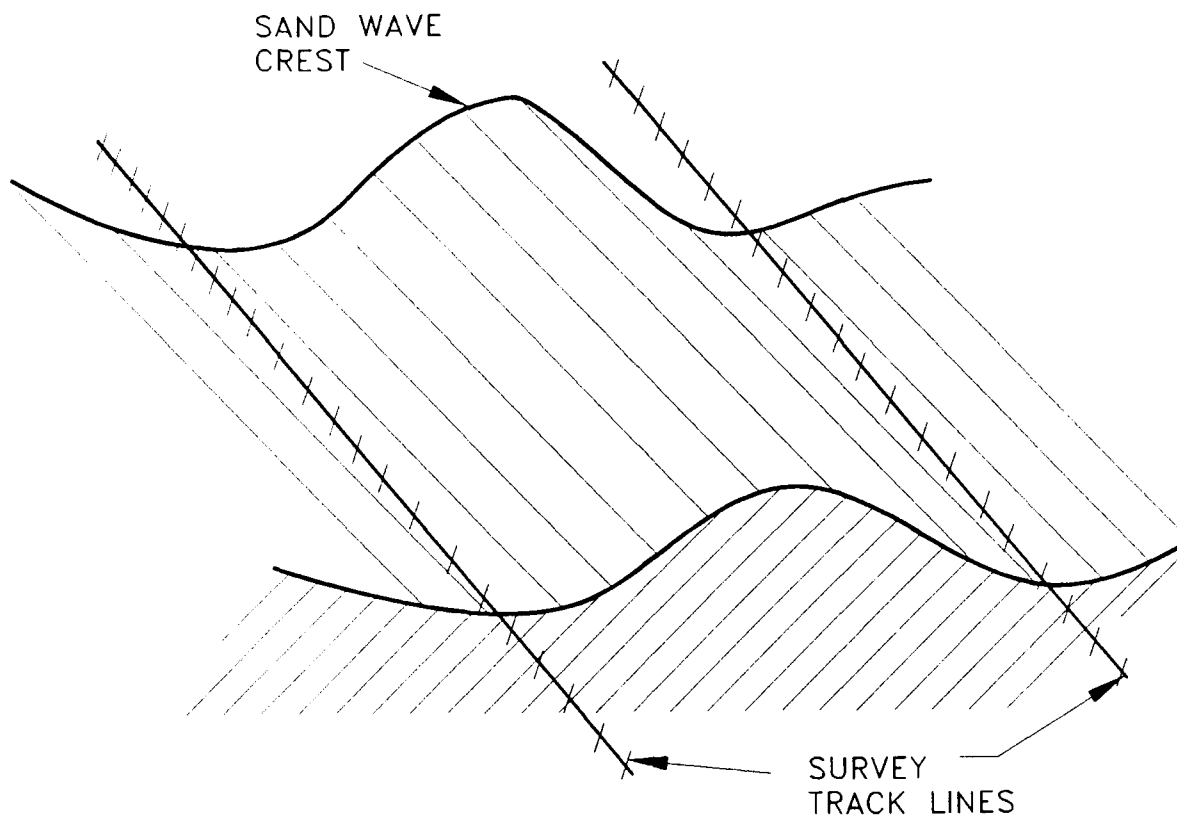


Figure 5. Survey track lines missing sand wave crest

accurate surveying techniques is in the common interest of both the dredger and waterway authority.

Guidelines for Surveying a Sand Wave-Prone Area

11. The Engineer Manual (EM) on survey and mapping (Headquarters, US Army Corps of Engineers (HQUSACE), in preparation) requires that payment surveys are to be of Class I accuracy. This limits horizontal position accuracy to within ± 5.0 ft and depth accuracy to within ± 0.5 ft. Class I accuracy further calls for survey line spacings not to exceed 100 ft for cross-channel surveying. For longitudinal (along-channel) surveys between channel toes, spacings are limited to 50 ft and side slope spacings are 50 and 25 ft, respectively, for 1V:3H and 1V:5H side slopes. A longitudinal survey follows track lines that run parallel to the channel, thus collecting data points across the crests and troughs of sand waves. Since sand waves develop and build in a perpendicular direction to flow, longitudinal or along-channel surveys can easily detect their presence. Automated onboard data processing

systems allow sand wave detection almost immediately if the track line runs perpendicular to the sand wave crests.

12. Ideally, cross-channel tracks should follow each crest and trough curvature location, as identified by longitudinal survey(s). The number and location of cross-channel track lines should be decided based on observed crest and trough locations while profiling. It may be easier to develop a data reduction technique that interpolates cross-channel crest and trough templates from a series of longitudinal track lines.

13. Standard hydrographic surveying system calibrations (HQUSACE, in preparation) should be performed prior to any payment survey. Other than calibration and control errors, water-surface wave action becomes the most important field error correction for sand wave surveying. Generally, a survey vessel will not be able to work in water with surface waves that are comparable in height and wavelength to sand waves that are causing navigation problems. Therefore, it will be fairly easy to distinguish wave action on the strip chart (or other type plot) as opposed to a large-scale bed form. Wave action should not be confused with actual bed forms. Where smaller bed forms such as ripples and megaripples (Lillycrop and Alexander, in preparation) are superimposed on the actual sand waves, it may be difficult or nearly impossible to distinguish them from surface wave effects. Fitting a smooth curve over the larger sand wave profile will produce an acceptable accuracy for subsequent volume estimates. In most cases the smaller bed form contribution will "average out" when a smooth curve profile is fitted over the sand wave. Figure 6 shows a typical sand wave fathometer chart trace with superimposed surface waves and suspected smaller bed forms identified.

14. Surface effects will be negligible for some situations, a calm day on a river, for example, but they must be accounted for in the majority of coastal and most estuarine environments. Although there are various methods and approaches for "smoothing" wave effects in hydrographic survey data, the best approach for sand wave surveying is to estimate the surface wave heights encountered during the survey. Wave data information can then be provided to office personnel carrying out data reduction. If field wave information is not available to personnel performing the data reduction in the office, graphical irregularities could be attributed to wave action, and the assumption that there is a flat channel bottom may completely hide the presence of bed forms during data processing. It is equally important not to use automated

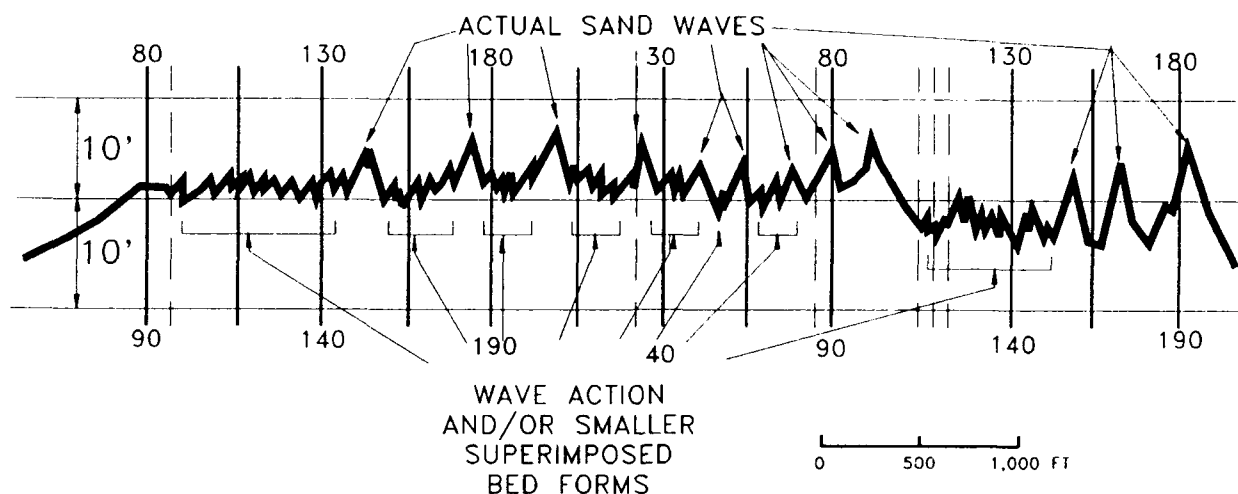


Figure 6. Fathometer strip chart showing sand waves in relation to wave action and/or smaller bed forms

linear regression techniques to smooth "wave effects" unless it is otherwise known that the waterway has a generally flat bottom. Should such processing take place before fathometer survey profiles are inspected visually, the presence of sand waves could go undetected. The most accurate technique would be to hand-smooth through the raw data trace based on field observation of wave heights (Figure 7) and then digitize the smoothed trace to more accurately represent bottom conditions. This technique will no doubt slow the data reduction process, but data reduction accuracy will be increased and considerable volume differences could be realized. Adjusting chart speed to produce an elongated profile on the horizontal axis may make this task easier.

Guidelines for Sand Wave Volume Calculation

15. Pay yardage for a dredging job can be calculated using a variety of methods and formulas, each with varying degrees of accuracy and complexity (US Army Engineer Division, Huntsville, 1988). Soundings can be collected and used to generate grids and networks via computer programs. Specialized software has been developed by various Corps Districts that incorporates local control that eliminates repetitive coordinate entry between successive surveys. Commercial software is also available and hydrographic surveying companies can supply data analysis software for specific applications. The selection of algorithms or computer programs to calculate pay yardage is a project management decision. It must be remembered, however, that no matter how

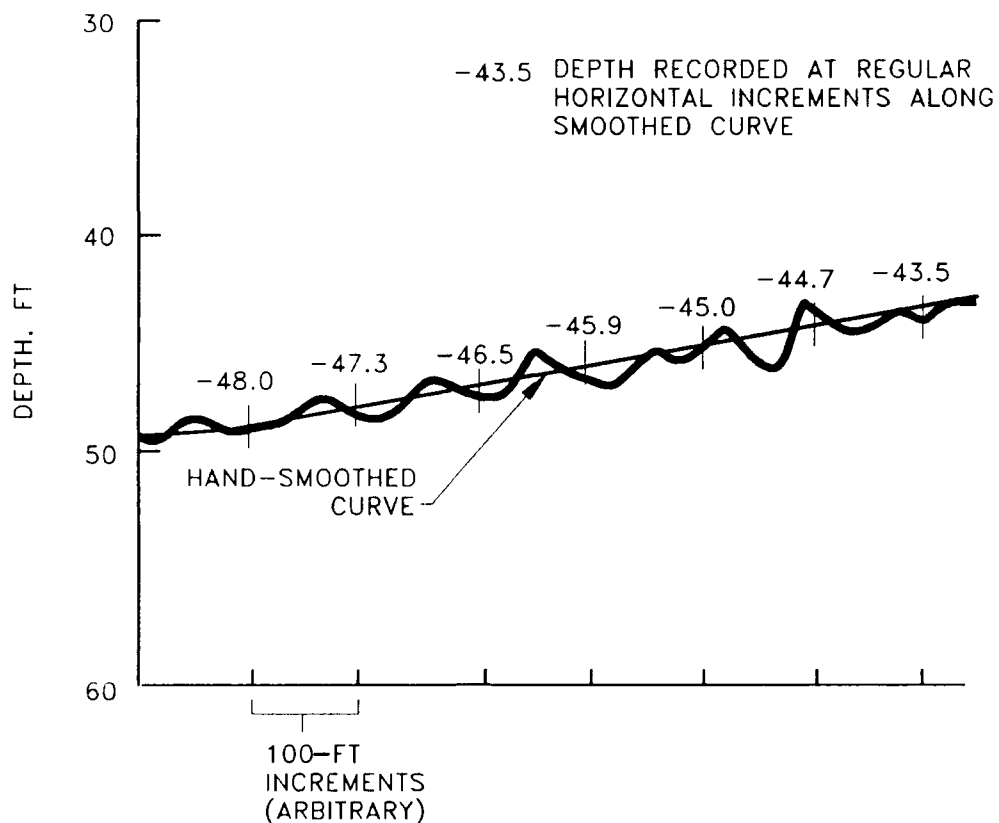


Figure 7. Hand-smoothed profile over wave effects

accurate and complex the yardage computation formula or procedure, accurate volume computation always depends on good field data collection.

16. The average end area method is the current Corps standard (HQUSACE, in preparation), as well as one of the most common yardage calculation formulas. This method is presented here to explain the concept of sand wave dredging volume calculations. A survey boat sounding a typical cross-channel track line in relation to authorized channel dimensions is shown in Figure 8. Figure 9 shows a typical channel reach for which volume is calculated with the average end area formula as follows:

$$V = \frac{\text{end area A-A} + \text{end area B-B}}{2} \frac{L}{27} \quad (1)$$

where

V = volume in reach, yd^3

A-A and B-B = respective cross-sectional end areas between actual bottom depth and channel template (Figure 8), ft^2

L = linear distance between sections A-A and B-B, ft

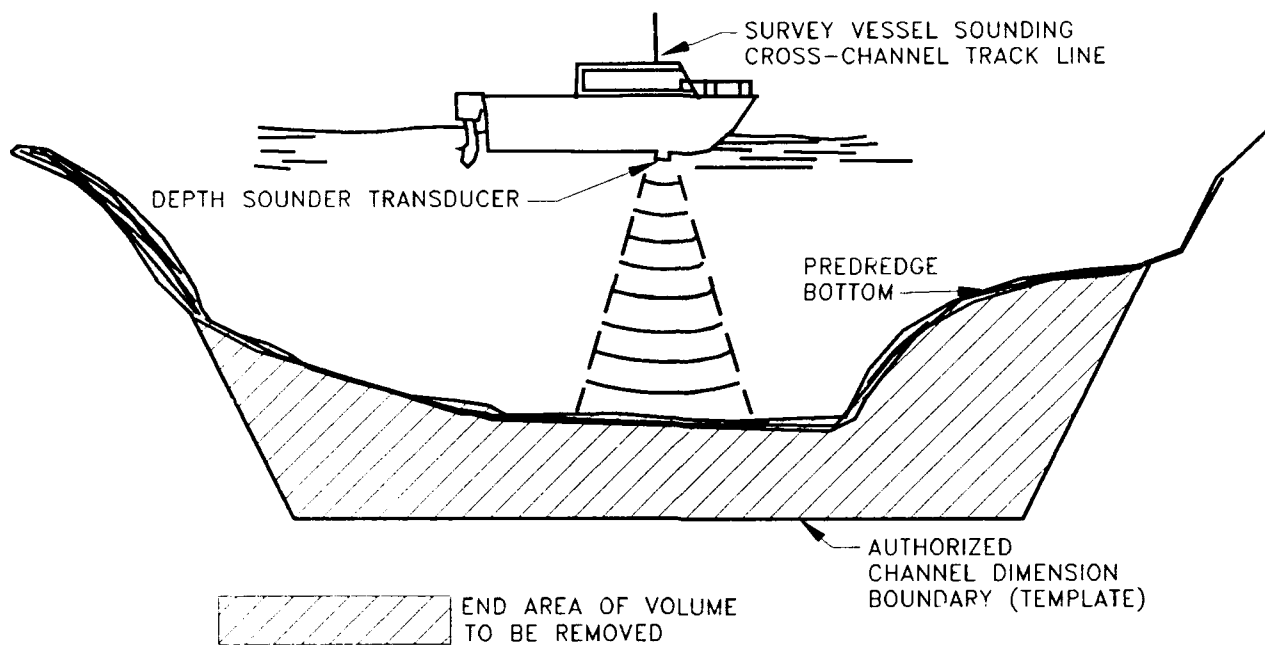


Figure 8. Cross-channel end area

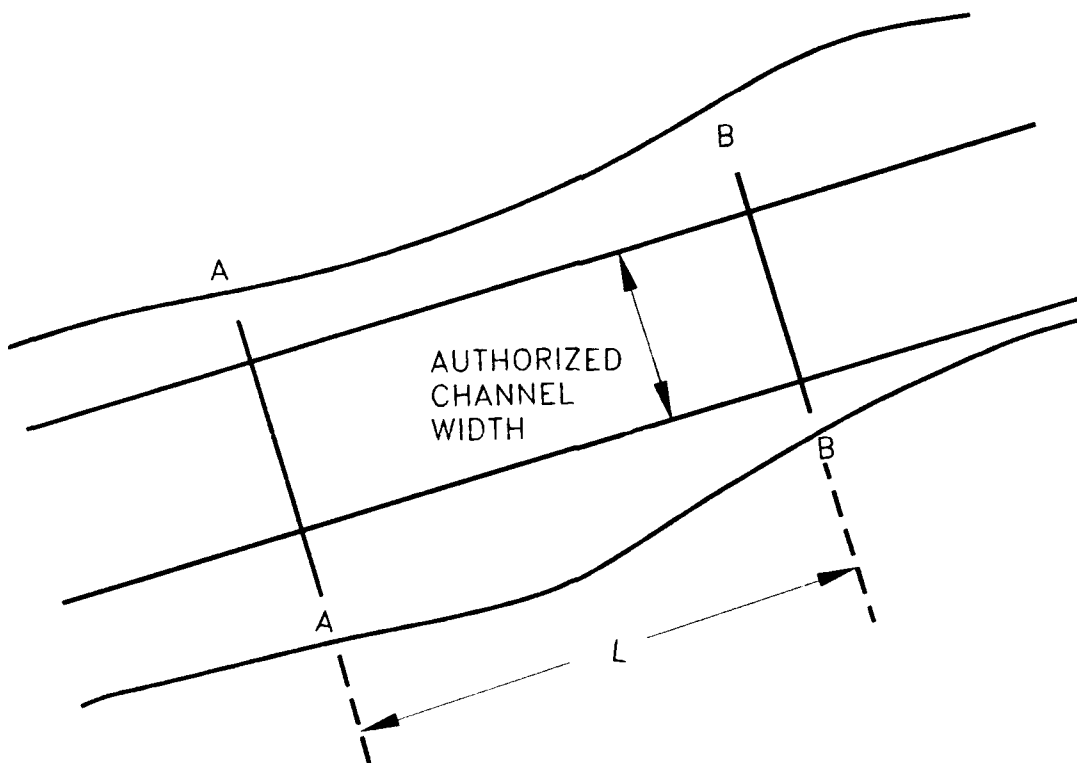


Figure 9. Channel reach between two cross-channel track lines at sections A-A and B-B

Division by 27 is to convert cubic feet to the more commonly used dredging unit of cubic yards.

17. This formula assumes a constant bottom slope between the two end areas. When calculating volumes over sand waves, it is important not to include void areas over the sand wave trough, or the actual volume will be overestimated. On the other hand, should a sand wave crest fall in the middle of two end areas, volume will be underestimated. The average end area method is accurate only if end areas are calculated at what can be considered "planes of inflection." Inflection planes are simply locations along the channel bottom where the bottom profile slope makes a significant change in direction. Inflection planes are described further in the following sections. Over long trough sections, several cross-channel tracks might be necessary.

18. Special cases for sand wave dredge volume calculations are described as follows:

- a. Case 1. Sand wave trough sections are well below project depth, but crest sections protrude above project depth (Figure 10).
- b. Case 2. Sand waves are present and trough sections are at or above project depth as well (Figure 11).

These two classifications are presented in order to bring attention to the sand wave mitigation concept as a whole. Sand waves are dynamic in nature and a mitigation technique can increase the dredging interval between extensive conventional operations. It is possible and likely at many locations to have a combination of these two cases. Other situations are possible such as the presence of sand waves entirely below project depth. Such a situation may develop into a case 1 or 2 problem. However, maintenance dredging would not be required until a case 1 or 2 situation actually develops, subsequently requiring a volume calculation described in the following paragraphs.

Case 1

19. Since only the crest portion of the bed form protrudes into authorized depth for a case 1 classification, the planes of intersection between the sand wave and channel template depth must be determined (Figure 10). Only the crest protrusion and any associated overdepth dredging volumes should be considered. Longitudinal surveys with areas calculated parallel to the direction of flow are essentially the only way to use the average end area method for a case 1 situation. Although it is possible to survey a case 1 situation with cross-channel track lines, it is much easier to obtain the protruding

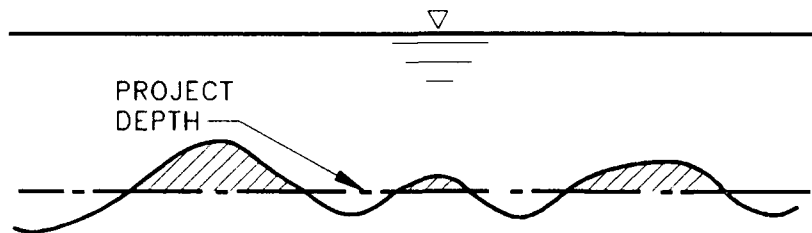


Figure 10. Case 1 sand waves

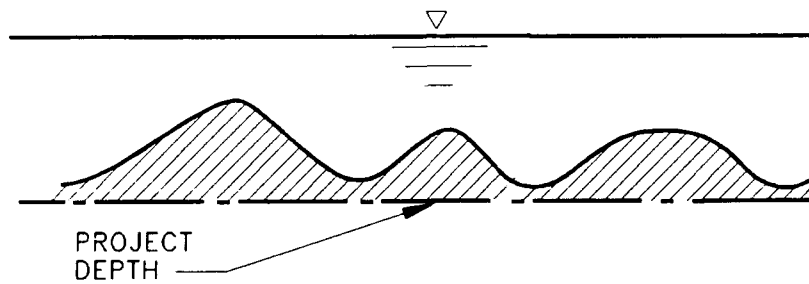


Figure 11. Case 2 sand waves

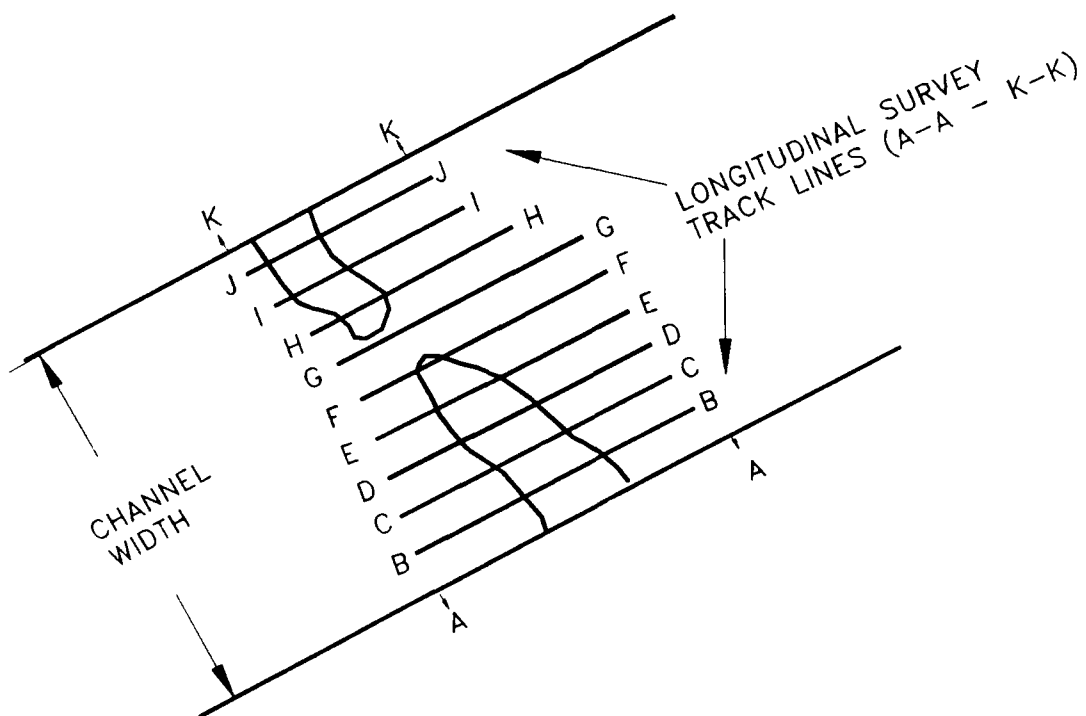


Figure 12. Case 1 sand wave with associated longitudinal survey track lines

sand wave profile with longitudinal surveying. The principles of volume calculation are the same except for the longitudinal orientation of the end areas.

20. Figure 12 depicts a plan view of a hypothetical case 1 sand wave encroaching across a section of navigation channel and corresponding longitudinal track lines. Track line spacing should be in accordance with the surveying and mapping EM (HQUSACE, in preparation). End areas at each section are calculated as shown in Figure 13 over the cross section of the sand wave. Each end area should be delineated into "segments," generally rectangles, trapezoids, and triangles. Care should be taken to arrange the segments to fit the end area as accurately as possible. This involves "fitting" the standard geometric shapes to minimize portions of excluded area due to curvature (also shown in Figure 13). (Graphical methods of fitting the segments can be well within the overall surveying system accuracy, but computerized segment fitting and subsequent end area/volume calculations can be much faster as well as more accurate.) Standard area formulas for triangles, trapezoids, etc., should be applied to the various segments and the values summed for the total end area. Increasing the number of segments over any lateral irregularities and curvature will minimize the error (indicated in Figure 13) and increase

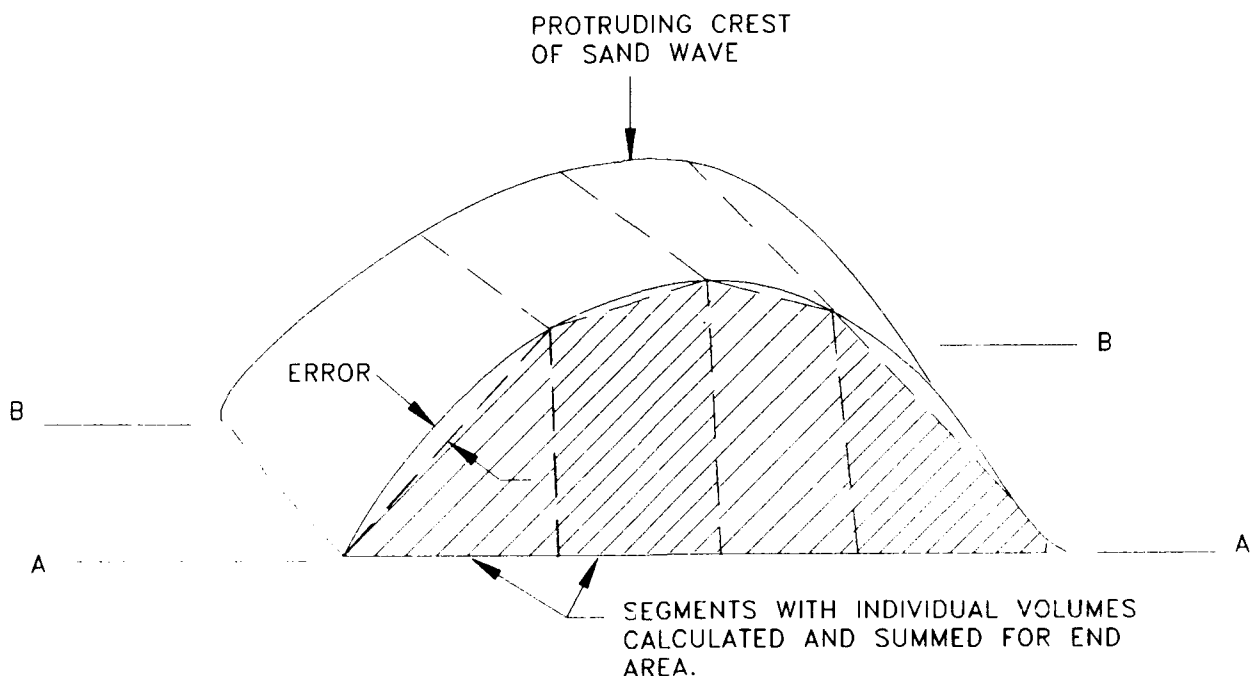


Figure 13. Portion of volume between track lines A-A and B-B (Figure 12).
Volume is summed laterally across the sand wave

computational accuracy. Calculated end areas can then be used with the average end area formula (Equation 1) across the width of the channel to determine the volume of the sand wave above authorized channel dimensions.

21. This approach will yield accurate yardage estimates for a single sand wave. Attempts to extend the end area across several sand waves in a localized area could result in significant errors. Individual sand wave volumes can easily be calculated and summed over a given area by computer. Computer codes can also be written to easily interpolate inflection planes at the intersection of the channel template and sand wave crest.

Case 2

22. A single case 2 sand wave is shown in relation to a dredging project template in Figures 14 and 15. Three cross-channel end areas are required to accurately calculate the volume over this sand wave. Case 2 sand waves can be surveyed in a longitudinal direction for volume computation as described for case 1. However, cross-channel surveys are standard practice among many Districts that compute dredge volumes, and longitudinal surveying may not be feasible over long stretches of channel. Provided that a limited amount of longitudinal surveying is carried out to identify sand waves and their inflection planes, the following series of guidelines will result in an accurate assessment of a case 2 sand wave volume.

23. For the case 2 sand wave shown, three end areas at the inflection planes shown in Figure 14 are necessary. End areas should be calculated at sections A-A, B-B, and C-C. As described in paragraph 20 for case 1 calculations, the end areas should be divided into segments over any irregularities and summed for an accurate total area. Once end areas are calculated, a volume estimate of the sand wave can be calculated with the average end area formula (Equation 1). The special consideration for case 2 sand wave volume computations is realizing the importance of properly located end areas. The following example illustrates this concern.

24. Suppose navigation difficulty has been reported over a certain 3,000-ft reach of river (Figure 16). Profile surveys have identified a series of three sand waves having case 2 classification. Sections A-A through J-J indicate necessary cross-channel survey track lines. End areas for sections A-A, C-C, D-D, F-F, G-G, I-I, and J-J were calculated for use with the average end area method (Equation 1) and equal $2,575 \text{ ft}^2$ each. If longitudinal surveys were not carried out and the track lines missed crest sections, the

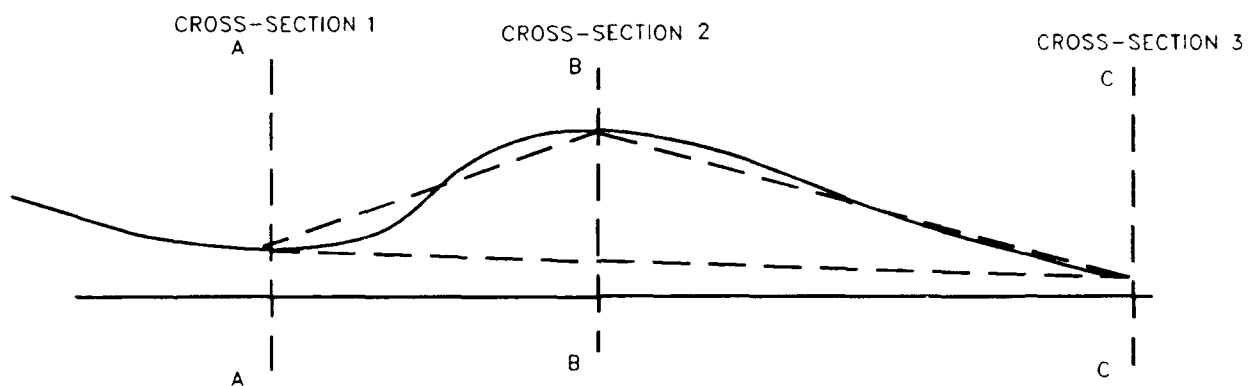


Figure 14. Case 2 sand wave and necessary end areas (located at inflection planes)

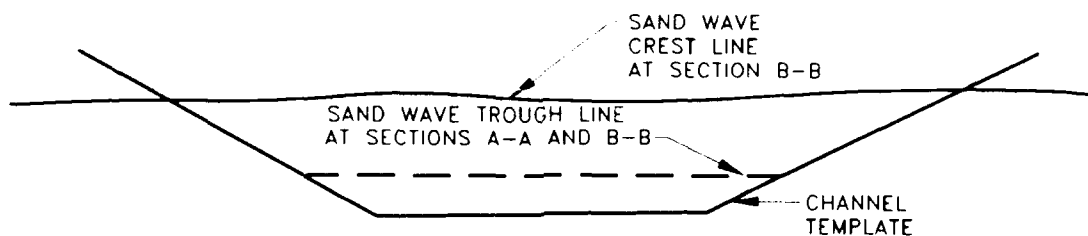


Figure 15. Cross section of Case 2 sand wave showing crest/trough heights above channel template

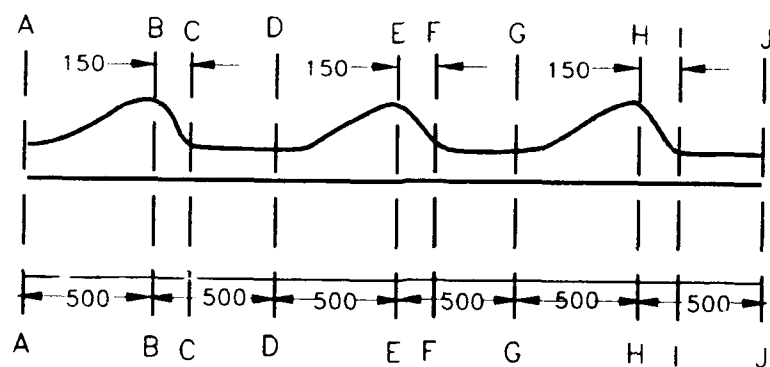


Figure 16. Example sand wave reach

dredging volume in this reach could be incorrectly calculated at 286,000 yd³. Such an oversight could result in underestimating the volume. With three sand waves present, each having a crest height of 5 ft (Figure 17), the volume would be increased by 33,000 yd³ for each of the three sand waves, resulting in a total correct volume of 385,000 yd³. Another situation such as cross-channel track lines spaced equally at 500-ft intervals would result in a volume of 438,000 yd³. This value includes an error of over 50,000 yd³. Therefore, by including track lines C-C, F-F, and I-I, resulting calculations do not produce such an error. Even more serious errors would be introduced should a trough section be missed altogether. Table 1 summarizes these situations. Note: System accuracies are beyond the scope of this example and only the survey errors that result from improper track line spacing are presented. Although this example is idealized, it can be seen that any number of erroneous dredge volumes could result from too few or incorrectly located survey track lines. Where sand waves are present, additional time and planning during the survey could be well worth the extra effort.

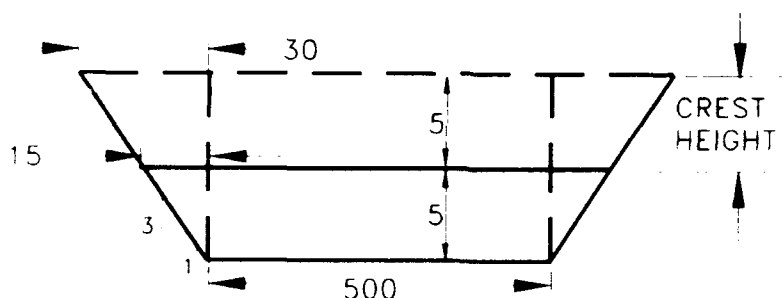


Figure 17. Cross-sectional view

Sand Wave Re-formation and Dredged Material Disposal

25. In rivers, estuaries, or coastal inlets with sand wave-conductive flow conditions, sand waves will form and re-form after dredging operations (Martin, Banks, and Alexander 1990; Lillycrop, Rosati, and McGehee 1989). The prerequisite for perpetual sand wave development in a channel with appropriate hydrodynamic conditions is a continuous influx of sand. Some areas may be source limited such as a coastal inlet with hydraulic conditions conducive to sand wave development. Here, a beneficial use of dredged material such as sand bypassing to a downdrift beach may prevent or sufficiently slow sediment influx, thereby saving sand wave dredging costs. Another option to limit

Table 1
Example Project Error Summary

<u>Surveyed Track Lines</u>	<u>Calculated*₃ Volume, yd³</u>	<u>Resulting Composite Error, yd³</u>
Actual Volume A-A - J-J, inclusive	385,000	None
A-A, C-C, D-D, F-F, G-G, I-I	286,000	100,000 (26% under)
A-A, B-B, D-D, E-E, G-G, H-H, J-J	438,000	53,000 (14% over)

* From Equation 1

sediment influx in coastal areas includes sealing jetties against sand intrusion. Generally, in a source-limited situation, the farther away dredged sand is placed or diverted from sand wave-conducive conditions, the better. Where sediment influx becomes impractical to alter, such as along a river reach, dredged sand wave material can be disposed of economically adjacent to the channel in open water. Hydrodynamic conditions and sediment influx causing sand waves in a given area create a complex and interrelated problem for maintaining navigation and are the focus of ongoing and future research within the sand waves work unit. Guidance for evaluating sand wave dynamics on a site-specific basis will allow an economic analysis of sand wave problem solutions, whether they be innovative or conventional.

PART III: CONVENTIONAL DREDGING TECHNIQUES
FOR SAND WAVE MITIGATION

26. The US Army Corps of Engineers maintains and operates only a minimal dredge fleet, and dredging contracts are routinely awarded to private industry contractors through competitive bidding. The Corps maintains inland, estuarine, and coastal waterways where a wide variety of materials and environmental conditions are encountered. Therefore private industry typically maintains versatile dredging equipment, enabling them to undertake a variety of dredging jobs with a limited number of dredge types. The high cost of designing and constructing a dredge plant makes the more conventional and versatile dredge types advantageous. However, sand waves create a specialized application for conventional dredge plants. Although conventional equipment can successfully remove sand waves, loss of operating efficiency is significant. Corps Districts with specialized sand wave dredging requirements must presently rely on generic equipment even though a more specialized design could regularly be used.

27. Many factors influence the efficiency and cost effectiveness of conventional dredging techniques and operations: type of sediment, pumping or haul distances, mechanical failure, relocation of equipment, and maintenance. Mobilization and demobilization (mob/demob) expenses can constitute a significant portion of a contract. Mob/demob costs vary between dredges, dredge type, and job location, but a point of efficiency (i.e., minimizing cost per cubic yard of material moved) can be reached between the amount of material to be dredged, the associated cost per cubic yard and the mob/demob costs. Efficient combinations of these factors become more difficult for the contractor and Government where sand waves are concerned because the problem shoals are "concentrated" at periodic sand wave crests. This leads to increased downtime due to relocating the dredge after removing a relatively small volume of material. The navigation problem may be just as severe as with any "linear" shoal, but the mob/demob percentage of the contract increases due to the limited volume of material. This leads to generally higher costs per cubic yard for sand wave dredging. When sand waves have formed and developed to the point where trough sections are above project depths (i.e., case 2), volumes increase and costs per cubic yard become more balanced. Conventional dredging operations are therefore most efficient for a case 2 situation, but must

presently be applied to any sand wave problem requiring dredging.

28. The following sections discuss efficient use of conventional dredge types for sand wave dredging. An attempt is made here to highlight advantages and disadvantages associated with using various conventional dredges for sand wave dredging, all other factors being equal. Dredge equipment availability as well as type in a given area are often controlling selection factors. Since mob/demob costs can be such a significant portion of a contract, a dredge close to a given job can be more cost effective than a more efficient type of dredge (in terms of production) with greater relocating costs.

29. Any of the various dredge types can conceivably and successfully remove a sand wave. However, only the types most applicable to sand wave dredging are discussed in this section. While the use of conventional dredge plants in a sand wave application is described in this part, Part IV describes the development of specialized dredges and/or procedures specifically for sand wave mitigation. More detailed descriptions of the dredging equipment discussed in the following sections can be found in EM 1110-2-5025 (HQUSACE 1983).

Hopper Dredges

30. Hopper dredges are self-propelled seagoing vessels that dredge bottom material through trailing drag arms. Their shiplike design and trailing drag arms allow operation in rough, open waters. The dredges are constructed with large bins or hoppers that hold the dredged material. When the hoppers are full, the dredge travels to a disposal site where the dredged material is either released through the bottom of the hoppers or pumped out to a land disposal site. Disposal can take place at any offshore or estuarine site, or the dredged material may serve a beneficial use such as beach nourishment. The hoppers are designed to allow excess water to overflow during dredging to maximize hopper solids. Hopper dredges are well-suited to dredging noncompacted maintenance materials. Since sand waves are generally composed of noncohesive moving sands, hopper dredges are quite capable of sand wave mitigation. Dredging is accomplished by (a) pumping past hopper overflow, (b) pumping through the hoppers as a form of agitation dredging, or (c) pumping to overflow.

31. Pumping to overflow would not normally apply to sand wave operations. This mode of operation becomes more important for environmental

concerns not generally associated with the noncohesive sands that compose sand waves. Pumping past overflow when dredging sand waves will essentially remove excess water from the hoppers, maximizing solids in the load. In an agitation mode, material is purposely pumped through the hoppers where ambient currents are used to transport material from the dredging prism. One former Corps hopper dredge, the *Langfitt*, was constructed with lower than usual overflow gates specifically for agitation dredging (Richardson 1984).

32. The *Langfitt* operated through the early 1980's at the mouth of the Mississippi River in conjunction with other dredges to keep the passages to the Gulf of Mexico open (Richardson 1984). This method has been successful at removing silt and clay-sized material, much smaller in grain size than the medium to coarse sand wave material. Suspended sediment travel distance becomes important when considering such an approach to sand wave dredging. Coarse grain sizes will resettle much faster than silts and clays. However, limited travel distance into an adjacent trough might justify hopper dredging in the agitation mode as a sand wave mitigation technique.

33. Disposal may also take place in a nearby trough section by positioning over the trough and releasing through the bottom or by agitation and ambient transport. Surveys must be recent and accurate for trough disposal to identify the location and capacity of trough sections. Dredge positioning during release is also important for this approach. A positioning error could compound the sand wave problem by releasing material at or too near an adjacent crest section. In terms of sand wave re-formation (paragraph 25), distant disposal may be an attractive hopper dredge characteristic. Hopper dredges can be mobilized great distances through open waters.

34. As with most conventional dredges, normal hopper dredge efficiency is reduced when used to mitigate sand waves. Figure 18 depicts a hopper dredge traversing a dredging area with the drag arms at a fixed depth. The

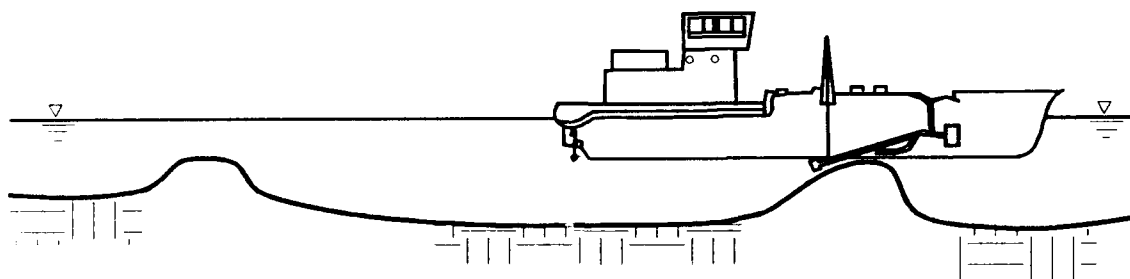


Figure 18. Hopper dredge working over sand waves

drag arms are lowered as work progresses to reach specified project depth. Dredging speeds are typically 2-3 knots, and a sand wave field creates an inefficient condition as excavation time is lost when the vessel travels over trough sections.

Cutterhead Dredges

35. Cutterhead pipeline dredges are generally the most popular and versatile type of dredge. Depending on the type of cutter, pipeline, and dredge size, the cutterhead dredge can remove a wide range of materials. Noncohesive (maintenance) materials as well as hard clays or even rock can be removed with a cutterhead dredge. This wide range of applications has made the cutterhead dredge the most popular among private industry (HQUSACE 1983).

36. The composition of sand waves poses no problem for cutterhead dredges (Figure 19). A cutterhead dredge can efficiently remove the relatively small volume of a single sand wave crest, but excessive downtime occurs as the dredge must be moved to the next sand wave crest location. Cutterhead dredges winch and manipulate themselves forward with spuds during dredging;

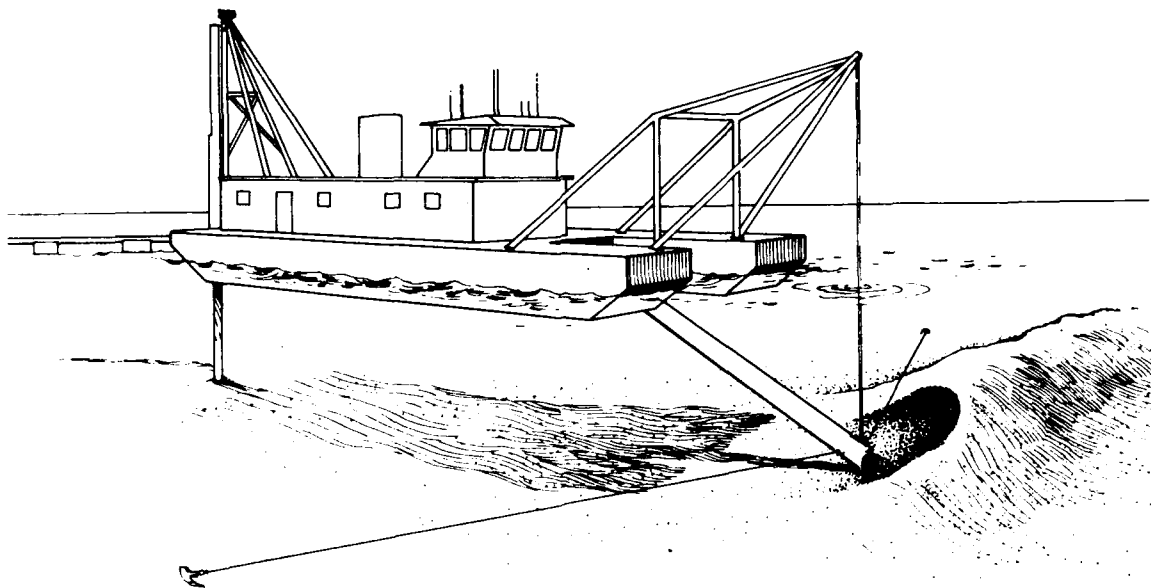


Figure 19. Cutterhead dredge removing single sand wave

therefore, each new dredging site requires that the dredge be reset, discharge pipeline reassembled, anchors and winch lines reset, and attendant plants moved.

37. Because most cutterhead dredges are not self-propelled, support vessels are necessary to transport the dredge. Relocation can be a time-consuming effort with cutterhead dredges since sand wave crest spacing can vary from several hundred to several thousand feet, and problem reaches may be multiples of miles apart in a river or estuary. Therefore dredge plant mobility is an advantage for sand wave mitigation. The cutterhead itself on a cutterhead dredge is not needed for dredging noncohesive sands. Plain suction pipeline dredges could be as efficient, but cutterhead operation is still necessary in noncohesive material to avoid obstructing material entrainment. Cutterheads are most efficient when a more continuous pumping cycle can be maintained. In general, a cutterhead dredge capable of operation in a deep-draft navigation channel is "overpowered" for case 1 sand wave situations. A case 2 situation offers more continuous operation and makes the dredging process more efficient.

Dustpan Dredges

38. The dustpan dredge was developed by the Corps of Engineers for maintaining channel dimensions on rivers during low stages (HQUSACE 1983). The dustpan dredge was designed to operate in sheltered waters, predominantly riverine systems with bed loads consisting of sands and gravels. Its high volume capability and the fact that it can remove a high lift of material at a sand wave crest (Figure 20), for example, make it an effective tool for sand wave mitigation. It is self-propelled and was designed to move quickly to problem areas over long distances. Dustpan dredge attendant plants and discharge pipelines are also designed for quick assembly, and the dredges can easily move to the side of the channel for passing vessels.

39. Dustpan dredges operate by making a series of parallel cuts in an upstream direction. Winch lines are anchored upstream of the dredging area, and the plant is winched forward during operations. Their wide suction heads (30 to 40 ft) work with a series of water jets that fluidize material as it is drawn into the suction head. Discharge distances are generally short (around 1,000 ft) and material is usually placed in open water outside the channel.

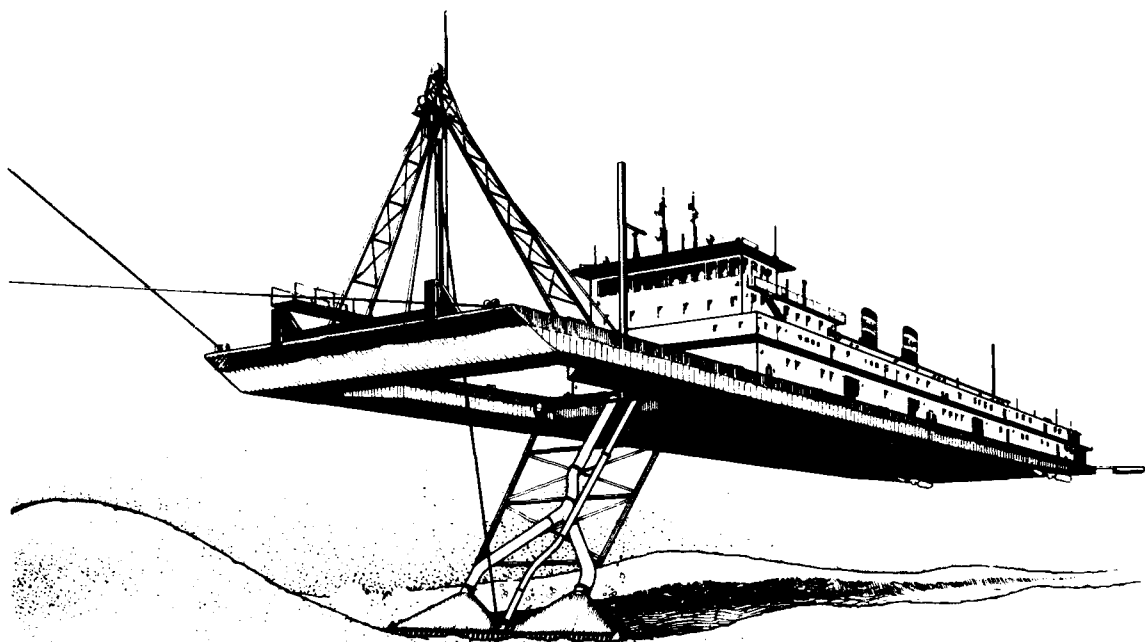


Figure 20. Dustpan dredge approaching sand wave crest

This approach can be very effective. The close proximity between dredging and disposal is insignificant due to the seasonal nature of most riverine dredging. Although some inland Districts reported having sand waves, few reported the need for improved sand wave dredging equipment when they currently carry out dredging projects with a dustpan dredge.* A new dustpan dredge is under construction for the US Army Engineer District, Memphis. This dredge will have a minimum production capability of 5,000 yd³ per hour (WODCON 1987).

40. With the seasonal stage variations on major rivers, sand wave problem classifications may vary between case 1 and case 2 as presented earlier. Mobility and the ability to remove a high lift of material make the dustpan effective at riverine channel maintenance, including sand wave mitigation. The limitation with dustpan dredge use is that it operates in calm waters. The design is not applicable to any significant wave environment. This precludes use at coastal, estuarine, and some riverine sites where rough waters are encountered. Environmental concerns at many locations may also disallow the type of open water material discharge used by dustpan dredges.

* G. A. Zarillo. 1988. "Evaluation of Corps of Engineers Questionnaire on Sand Waves," unpublished letter report, Florida Institute of Technology, Melbourne, FL, for Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bucket/Clamshell Dredges

41. Bucket (or clamshell) dredging is one of the oldest and simplest dredging concepts. Bucket dredging production is relatively slow compared to hydraulic pipeline dredges. It is not expected that bucket dredging will be widely used for sand wave mitigation, but it may be a cost-effective alternative for some situations due to low mob/demob costs. Bucket dredging may prove economical for a single or limited number of case 2 sand waves (Figure 21). Where a small volume of crest material is creating impedance to navigation, the bucket dredge may be able to remove the crest and swing the material into an adjacent trough or other nearby disposal site. Where swing distance is insufficient, a barge or scow may be necessary to transport dredged crest material into an adjacent trough. Material may also be pumped from the barge/scow to any specified disposal site.

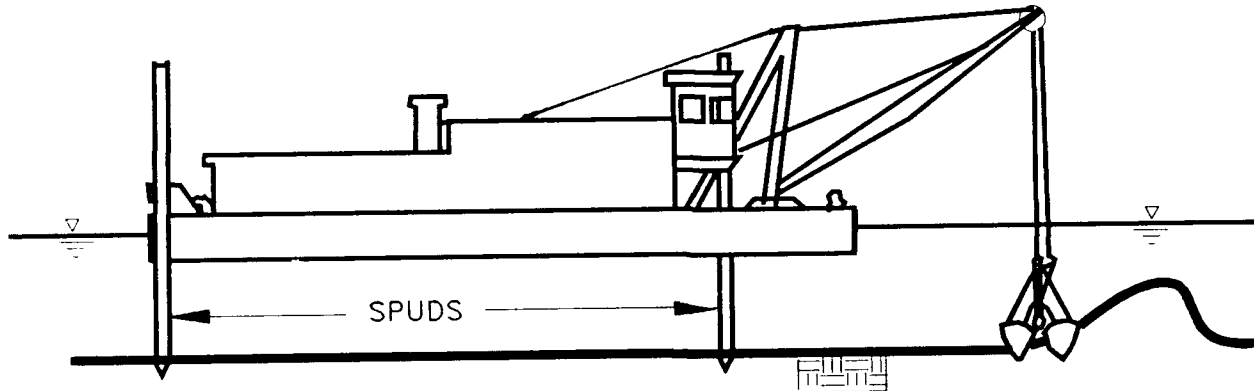


Figure 21. Bucket dredge removing sand wave crest

PART IV: INNOVATIVE SAND WAVE DREDGING TECHNIQUES

Background

42. The unique physical characteristics of sand waves fitting the case 1 classification lend themselves to less expensive leveling techniques. Where sediment influx is a given, the aim of improved sand wave reach dredging is to prolong the interval between conventional dredging operations by using below-project-depth trough sections as disposal sites for adjacent crest shoals. This can be accomplished by leveling sand wave crests hydraulically, mechanically, or by a combination of both. Given the typical profile of a case 1 sand wave in a navigation channel, logic dictates that project depths can be restored by moving the crest material into the trough, thereby producing a "flat" bed either at or below project depths. Although the concept is easy to understand, accomplishing this task easily and economically presents a challenge. This section of the report discusses innovative techniques and approaches to bed form leveling between more extensive dredging operations.

43. Some of today's innovative concepts for sand wave dredging can be traced back to the 1860's when scraping devices were employed on the Mississippi River. Ockerson (1898) describes some of these early dredging techniques: a boat equipped with a scraper frame on the bow moved to the upstream end of a "crossing," lowered the scraper frame, and then backed slowly downstream, scraping sediment with it into the "pool" below the crossing. Such dredging operations were successful at increasing navigable depths by up to 1.5 ft. Scraping is still an example of a viable concept for sand wave dredging today.

44. In the late 1800's, research aimed at maintaining navigable depths during low water on the Mississippi River studied the use of scraping, stirring, and mixing devices. This early research concluded that in order to agitate the bottom by some mechanical means such as water jets, harrows, or plows, it must be presumed that the sand, agitated and thrown up into the water column, will be carried off by the ambient current. It was further concluded that it is comparatively easy to agitate or stir up the bottom, but that ambient currents are inadequate to transport the agitated sediment, except under very favorable conditions. For rivers, favorable conditions would mean high stream velocities associated with spring freshets or floods.

Such favorable conditions may never be attained at tidal inlets in coastal areas. In order for sand to be transported any considerable distance downstream, strong ambient current velocities are necessary. Based on the present level of knowledge of sand wave dynamics, these favorable ambient forces, in terms of transporting agitated sediment, are also the generative force behind sand wave development. On rivers, a more successful technique would be to level sand waves during the onset of low stream power conditions to take advantage of the interval between hydraulic conditions conducive to sand wave development (high flows) and conditions that are below significant bed load transport (low flows).

45. Aside from episodic storm events, the hydraulic conditions at many coastal areas are more periodic. Design modifications (i.e., channel dimensions) could be considered at both coastal and riverine systems before using a leveling technique in an area with rapid sand wave re-formation time. Where sand waves are determined to build more slowly, a leveling technique may be cost effective between more extensive dredging operations.

Agitation Techniques

46. As described in Richardson (1984), current agitation dredging technology seems to use the same brute force techniques that were used (with limited success) prior to development of the hydraulic pipeline dredge. A form of agitation dredging is the premise for extending the conventional dredging interval for sand wave-prone areas. Vessel propwash techniques are described by Richardson, but are usually most applicable to shallow harbors and berths. A narrowed portion of the authorized channel width may be inadvertently "maintained" by passing vessel action and associated propeller wash. This can allow a more lengthy dredging interval and result in a case 2 dredging scenario later on. The following sections describe systems and techniques specifically designed for agitation dredging.

47. Recent agitation dredging research has taken place in Europe (Meyvis and Marain 1988) dealing mainly with silts and muds. The difficulties encountered with this research parallel those with sand wave agitation: ambient currents are generally insufficient to carry thixotropic muds, as well as coarse sands. An experimental forced air and water jet boom was developed and tried in an effort to suspend the muds. Water jet action was intended to

fluidize the material and air bubbles rising through the water column were intended to raise the mixture high enough in the water column so that it could be carried away by ambient forces. This device did not prove effective at suspending material in the water column. Its limited success was due to raking action (Meyvis and Marain 1988). Water injection techniques alone have also been developed in Europe, and paragraphs 54-56 describe the production agitation dredge *Jetsed*. The US Army Engineer District, Portland, also has experience with a water injection sand wave dredging vessel (paragraph 57). Figure 22 depicts the experimental water jet boom used on Columbia River sand waves during the Portland District exercises.

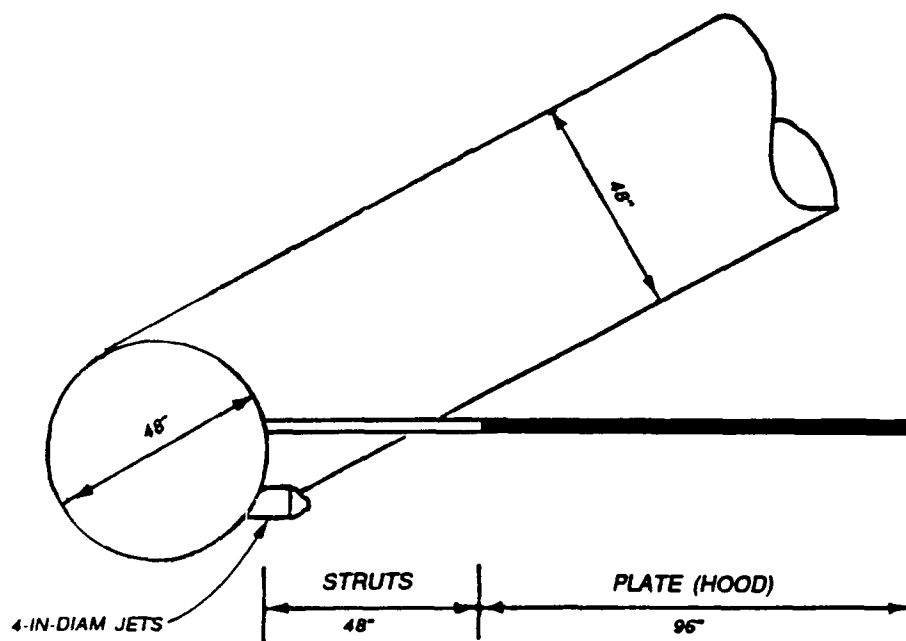


Figure 22. Side view of sand wave fluidizer boom

48. As would be expected, the most successful scraping techniques are carried out in areas with fine-grained noncohesive materials where ambient forces are sufficient to move the agitated sediment into deeper waters (Richardson 1984). Although some of these criteria are met in a typical sand wave reach, the sands can be large in grain size or gravelly and therefore too "heavy" for significant ambient current transport.

49. Various farm harrows, rakes, and I-beams have been and continue to be used and experimented with at small-scale dredging projects (Figure 23). Such methods are applicable to case 1 sand waves. Testing was carried out by the Portland District in 1971 (Lagasse 1975). In an attempt to remove small-scale sand waves, one of the District's small tugs was fitted to pull a

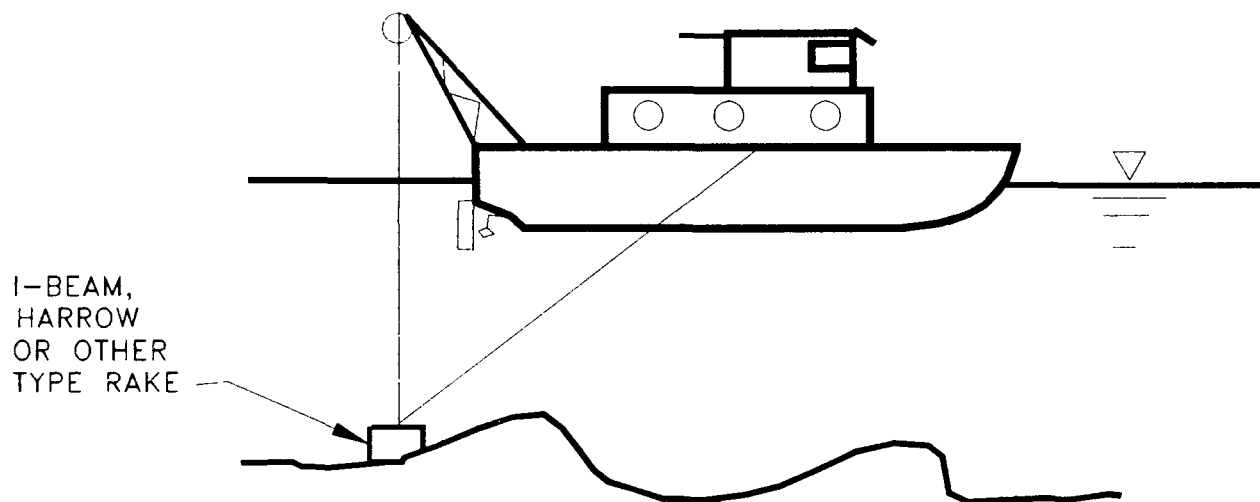


Figure 23. Tug-powered agitation dredging concept

standard agricultural-type harrow over a selected shoal. The tests were carried out over a 2-month period and were estimated to have successfully removed about 50,000 yd³ of material at a cost well below that of hydraulic pipeline dredging. The concept of using a bed leveler in conjunction with hopper (Van de Graaf 1986) or other conventional dredging may become feasible for sand wave mitigation. Van de Graaf points out that hopper dredge operational efficiency can be improved by using scrapers with conventional hopper dredging. Improving scraper designs and capacity may result in developing a successful mechanism for sand wave leveling. European scraper technology includes unique design features and advantages as discussed in the following sections.

Sweep Beam

50. Underwater bed form "bulldozing" has been informally discussed among various Corps researchers. Ideas to carry out such research vary, but sufficient force and vessel wheel power must be applied to obtain any degree of success. Belgian "sweep beam" maintenance dredging is an example of a promising technique (Meyvis and Marain 1988). The sweep beam is a 72-ft-long, 15-ft-high, and 10-ft-deep steel structure equipped with a bulldozer blade. The beam is also constructed with float tanks that can be filled with air or water as required for proper ballasting. The beam, which weighs 24 tons, is deployed from a ship with cables and winches and is pulled along the bottom of a channel. Just as with land dozing equipment, sufficient mass is required to oppose and level an underwater bed form.

51. After a sufficiently sized and weighted dozer beam is designed, an appropriate vessel must be used to pull and maneuver it in a dredging application. Ballast tanks may be required such as with the Belgian leveler. Initial trials for the sweep beam discussed in the preceding paragraph were carried out using a conventional hopper dredge as the support vessel. The hopper dredge and its winching system proved adequate for this operation. Total vessel power used during the trials ranged between 1,000 and 2,000 hp. Depths were increased up to 2 ft. Additional related testing also proved that smaller tugs are not as capable of handling such a scraper device. A smaller type of sweep beam was designed and used with a 750-hp tug. Winching and maneuverability power proved inadequate for the smaller version of the sweep beam (Meyvis and Marain 1988).

52. It was concluded from the sweep beam tests that thixotropic muds can be pushed for long distances in front of the beam, and that system efficiency is a function of beam frontal surface area. Excluding mob/demob costs, bed levelers can have higher costs per cubic yard of material moved than conventional dredging. However, such an alternative might prove more economical when mob/demob expenses are included (Van de Graaf 1986). A specially designed handling vessel having nearly the same propulsion power as the hopper dredger was designed and is currently used to handle the beam.

Water Injection Dredging

53. The term water injection dredging is used here to describe the agitation, suspension, and/or force (fluid momentum) exerted by water jets as a dredging technique. Since the technique is a form of agitation dredging, ambient current transport is an important consideration. High-velocity agitation dependent on ambient current transport has been developed successfully in fine-grained material (Estourgie 1988). Two dredging vessels are discussed in order to describe these concepts from a field operations viewpoint.

The Jetsed

54. The *Jetsed* is a self-propelled water injection agitation dredging vessel designed, built, and licensed by Volker Stevin Dredging, The Netherlands (Estourgie 1988). It is 90 ft long and 46 ft wide. A central pipe is

raised/lowered between its catamaran hull (Figure 24), which supports a 46-ft-wide agitation boom. Supply water is pumped through the pipe and boom where jet nozzles evenly distribute the water force. Two supply pumps operate in parallel for a combined flow to the boom of $118 \text{ ft}^3/\text{sec}$ at 22 psi. Separate engine/propulsion units are located on both the starboard side of the bow and the port side of the stern allowing excellent maneuverability.

55. The concept behind the *Jetsed* operation is to create a density or turbidity current. During dredging, water injection creates a water-sediment mixture of extremely low viscosity. The thickness of the layer will vary due

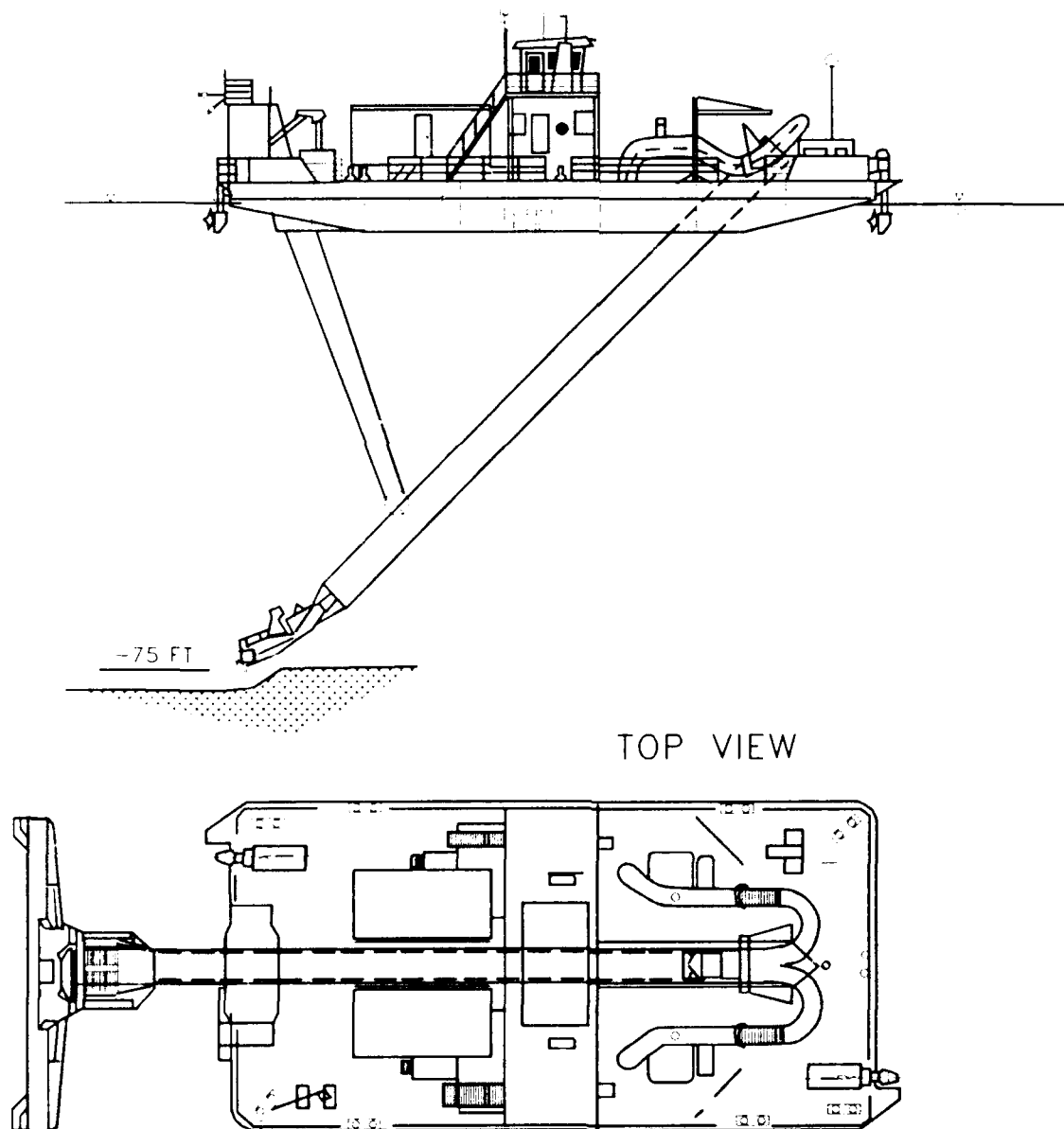


Figure 24. Water injection dredging vessel *Jetsed* (Courtesy of A. L. P. Estourgie, Volker Stevin Dredging)

to sediment characteristics but may develop as thick as 10 ft (Estourgie 1988). This procedure is effective where natural ambient forces can carry material away to settle in deeper waters.

56. The *Jetsed* has successfully dredged dense, fine sand with a production rate of approximately 1,000 yd³/hr. In coarse, gravelly Rhine River sands ranging from 0.2 to 14 mm (D_{50} 8 mm), *Jetsed* production averaged 650 yd³/hr with the aid of ambient currents.*

Sand Wave Skimmer Anderson

57. The sand wave skimmer dredge *Anderson* was constructed by Western Pacific Dredging Company specifically for sand wave mitigation on the Columbia River. The dredge was originally a conventional cutterhead that was converted into a jet fluidizer. The normal flow direction was reversed to supply high-pressure outflow to a 60-ft horizontal boom fluidizer with nozzles on 6-ft spacing (Figure 25). Testing was carried out in 1987 and 1988 in conjunction with the Portland District on a series of sand waves in the Columbia River (Martin, Banks, and Alexander 1990; Granat and Alexander, in preparation). Hourly production varied from a few hundred to several thousand cubic yards per hour. General conclusions were that (a) the dredge's agitation capability

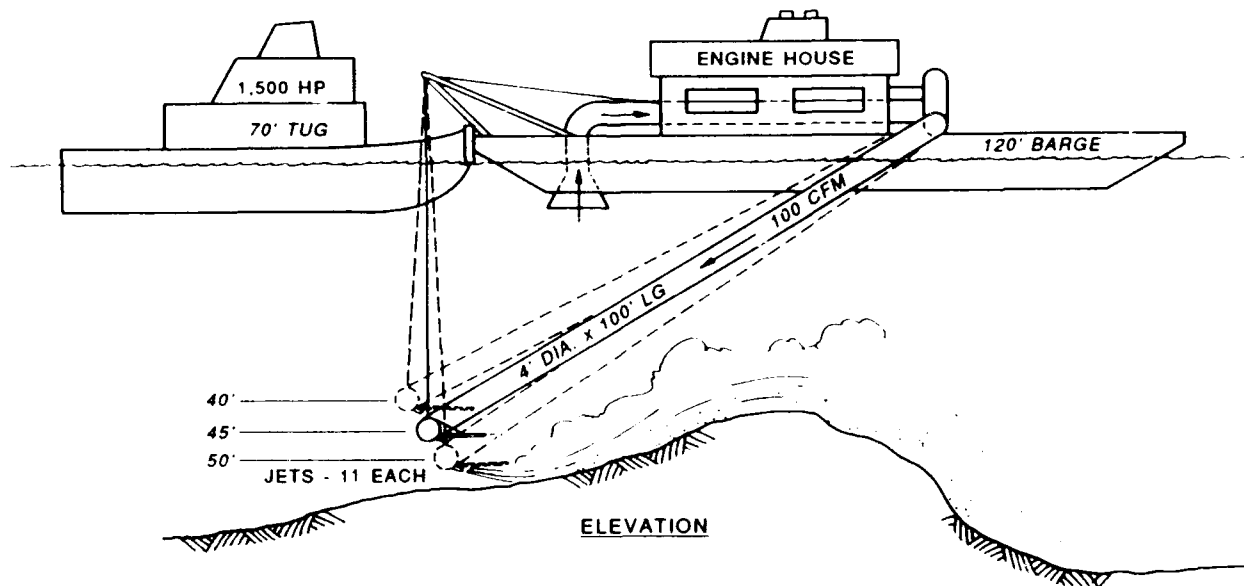


Figure 25. Sand wave skimmer *Anderson*

* From unpublished correspondence with Volker Stevin Dredging, 14 February 1989, Rotterdam, The Netherlands.

was insufficient to suspend the coarse sands encountered any higher than a few feet above the boom; (b) positioning the vessel was very difficult with the tug, which made the high production rates short-lived; and (c) ambient currents were slow (1-2 fps), and subsequently provided little assistance with suspended sediment transport distances. Some degree of effectiveness was obtained by the boom's raking action over the crests of the sand waves, although it was not designed as a scraping device. Although the concept proved effective, the costs of the vessel as compared to more conventional dredging are not competitive. However, design modifications and improved maneuverability could maintain higher production rates, making this dredging concept cost effective. For more complete details on these exercises, refer to Martin, Banks, and Alexander (1990) and Granat and Alexander (in preparation).

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

58. Sand waves have been identified as a distinctive shoaling problem where conventional hydrographic surveying and dredging practices are not always cost efficient. Large differences in calculated dredging volumes can result from failure to compensate for the presence of sand waves. Once accurate volumes are calculated, the actual dredging of sand wave problem areas is often operationally inefficient due to the current designs of conventional dredges and their application to the unique shape and spacing of sand waves. Only limited research and development in the area of specialized sand wave dredging have been conducted. Before a dredge or dredging technique can be successfully designed, sand wave formation under natural conditions must be better understood.

Recommendations

59. The following recommendations are made for determining the presence of sand waves:

- a. Conduct longitudinal condition surveys of all dredged navigation channels to determine if sand waves are present.
- b. If sand waves are present, use methods presented in this report to survey the bed forms and calculate dredging volumes.

60. Two approaches are being pursued to develop methods to mitigate sand waves in navigation channels: establishment of design criteria to minimize sand wave formation and improved dredging techniques. Continued research will address the following topics:

- a. Continue basic research into the formation of sand waves under natural conditions.
- b. Develop design guidance for site-specific applications to evaluate the feasibility of a specialized sand wave mitigation technique. This will include hydrodynamic alterations and dredging (maintenance) options. Empirical and analytical techniques will be incorporated.
- c. Once basic research has been conducted, evaluate possible dredging techniques and designs to efficiently dredge sand wave-prone navigation channels.
- d. Develop a conceptual design of a sand wave dredge.

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